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INFRARED OBSERVATIONS OF DIFFUSE BACKGROUNDS

MARTIN O. HARWIT, JAMES R. HOUCK, BARRIE W. JONES,
JUDITH L. PIPHER, and BARUCH T. SOIFER

Center for Radiophysics and Space Research, Space Science Building
Cornell University, Ithaca, N. Y. 14850

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Martin O. Harwit
James R. Houck
Barrie W. Jones
Judith L. Pipher
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This report consists of two parts and represents two scientific papers which present the results obtained in our December 2, 1970 flight.

A) Rocket Infrared Observations of the Interplanetary Medium

B) Submillimeter Observations of the Night Sky Emission Above 120 Kilometers.

The first of these papers has been submitted for publication to the Astrophysical Journal Letters. The second paper is to be published in the journal Nature.

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ABSTRACT

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A. ROCKET INFRARED OBSERVATIONS OF THE INTERPLANETARY MEDIUM

Baruch T. Soifer, J.R. Houck*, Martin Harwit

Abstract

Upper limits on the diffuse background radiation in the intermediate infrared ($5\mu \leq \lambda \leq 23\mu$), as measured from a sounding rocket, are presented. Evidence is given for the detection of thermal emission from the interplanetary medium.

* Alfred P. Sloan Research Fellow

Introduction

On 2 December 1970 a liquid helium cooled telescope was carried to a peak altitude of 190 km by an Aerobee 170 rocket from White Sands, New Mexico. This paper reports the observed backgrounds for the three short wavelength detectors ($5\mu \leq \lambda \leq 23\mu$). A comparison of the observations and models of the interplanetary medium is presented. Pipher, et al. (1971) have discussed the observed backgrounds for $60\mu < \lambda < 1500\mu$.

The optical system consists of a prime focus telescope D = 6.75", f = 0.9) and is described in detail elsewhere (Pipher, et al. 1971, Harwit, Houck, Fuhrmann 1969). The three short wavelength detectors flown were copper-doped germanium photoconductors fabricated in the manner described by Quist (1968). The spectral bandpasses were defined by the characteristic Ge:Cu response and interference and blocking filters. The spectral response of each detector-filter system was measured using a Perkin Elmer 301 Far Infrared Spectrophotometer. The sensitivity of the systems in the flight telescope was determined by the calibration procedure described by Harwit, Houck, and Fuhrmann (1969). Absolute calibration errors are difficult to determine. We believe, however, that our uncertainties are less than a factor of 2. The first three columns of Table 1 give the wavelength ranges and sensitivities of these detectors. Also included is the same data for one of the submillimeter detectors, a Ge:Ga photoconductor.

The Flight

The rocket was launched at 01:32 MST on 2 December 1970, and reached a peak altitude of 190 km at +225 sec. A roll stabilized

Attitude Control System (ACS) was used to point the telescope, and the position was monitored by an aspect camera. The path scanned in the sky from nose cone eject at 110 km (+110 sec) to +250 sec is shown in Figure 1. At +227 seconds a failure in the ACS system caused the payload to tumble for the remainder of the flight. The pointing direction of the telescope was determined from the aspect pictures until +250 seconds; only data obtained before this time is used in the analysis.

Results

(a) Backgrounds

Table 1 lists minimum fluxes observed during the flight. Also listed are the minimum signals with the contribution from scattered earthshine subtracted as described below. These are thus the minimum signals detected in the flight and as such are upper limits to the celestial background.

The earth, if viewed directly by the telescope, is approximately 10^8 times brighter in the $5\mu \leq \lambda \leq 23\mu$ range than the upper limits in Table 1, so the contribution of scattered terrestrial emission to the signals may be sizable even for a well baffled system. Therefore knowledge of the baffling function (i.e. beam pattern) of the optical system is required. Because the telescope is helium cooled and cannot be opened in the atmosphere, the baffling functions for the detectors could not be measured under flight conditions. Instead, the baffling was calibrated in the laboratory, with the instrument at room temperature, and using visible light. At large zenith angles the observed flux vs. zenith angle curve agrees well with that obtained

by convolving the calibrated baffling function with the geometry of the earth for the Ge:Ga detector. For the three Ge:Cu detectors the slopes agree well, however the measured radiation is about a factor of 10 lower than that predicted. Figure 2 shows the observed flux as a function of zenith angle for the 16-23 micron detector. BB' is the computed baffling function fitted to the data at very large zenith angles. This plot is typical of all the detectors.

(b) Zodiacal Emission

During the period from +200 sec to +250 sec, there is more diffuse radiation at small zenith angles and all wavelengths than that predicted from scattered earth light. A number of individual sources were also observed and the reduction of these data is in progress. In Figure 2 this excess diffuse radiation is plotted versus zenith angle for the 16-23 micron detector. Because the field of view of each detector is $1\frac{1}{2}^{\circ} \times 1\frac{1}{2}^{\circ}$ square and the uncertainty pointing direction is $\sim 1/2^{\circ}$, we consider it significant that all the excess fluxes in pass 2 peak within 2° of the ecliptic plane. Figure 3 shows plots of excess flux vs. ecliptic elevation angle for the 12-14 micron and 16-23 micron detectors.

The scanning pattern of the flight took the telescope across the ecliptic plane twice during the flight. During the first pass, dust particles carried up with the vehicle appear to have been drifting across the field of view of the detector. (Local dust grains are recognized by their large signal size, apparent spinning motion, velocity and spin rate consistency and simultaneous appearance on all channels.) The smallest signals observed within 5° of the ecliptic plane on pass 1 (Table 1) are presented as upper limits.

There does not appear to be a correlation between the excess flux observed in the second scan and the rocket altitude for any detector. The slow variation of signal with time seems to rule out dust grains, carried up with the vehicle, as the source. We cannot positively rule out upper atmospheric emission as a source of some of the flux observed. The fact that the excess flux reached a maximum within 1/2 km of the maximum altitude of the rocket, for all the detectors, is a strong argument against its origin being in the upper atmosphere.

Discussion

The estimates of emission from the ecliptic plane are listed in Table 1 and plotted in Figure 4. Our upper limits from scan 1 are consistent with the data from scan 2. In what follows, only the data from scan 2 will be used. For the $70\mu \leq \lambda \leq 130\mu$ band no attempt has been made to correct for contribution from a galactic background. This could lower the quoted value by a significant fraction (Pipher, 1971). The Ge:Ga detector is sensitive to emission from zodiacal particles at larger distances from the sun (cooler particles) than are the Ge:Cu detectors. These two effects would tend to raise this point above a blackbody curve drawn for the 3 Ge:Cu detectors.

Taking the observed upper limits from the second pass, one can roughly calculate the total thermal emission of the zodiacal particles. For blackbody emitters at a temperature ranging from 230°K to 350°K, the flux in the 12-14 micron band is (11±1/2)% of the total emitted energy, so our estimate of the total emitted flux of 1.2×10^{-9} watts/cm^2 str is quite insensitive to grain temperature. This flux can be compared

with the scattered visible radiation at the same elongation angle, $\epsilon \sim 160^{\circ}$, of $\sim 2\times10^{-10}$ watts/cm^{2}str (Allen, 1964). If one assumes that the grains scatter isotropically, with an added fraction α in the forward and backward directions

$$\alpha = \frac{\text{Flux scattered forward+backward}}{\text{Flux scattered isotropically}}$$

then the total flux scattered by the grains is $(1+\alpha)\times2\times10^{-10}$ watts/cm^2 str. Then the ratio of these two fluxes, i.e. $\frac{\text{Flux scattered}}{\text{Flux emitted}} = \frac{\text{Solar Flux scattered}}{\text{Solar Flux absorbed}}$ is $\sim 0.15(1+\alpha)$. With $\alpha \sim 1$ this ratio becomes $\sim .3$ which is not unreasonably large for typical particles. These results are derived assuming blackbody emission by the radiating particles. The total flux emitted should not be strongly affected by a nonconstant (in λ) emissivity, as long as particles have diameters of 2.5μ and larger.

As a comparison, recent infrared observations of comet 1969g and comet 1969i by Kleinmann, et al. (1971) yield a ratio of total scattered to total absorbed solar flux in cometary nuclei of 0.3 to $0.6(1+\alpha)$ where α is the same parameter defined above. This total scattered sunlight was determined by fitting a solar spectrum to the data of Kleinmann et al. (1971) in the 1.25-1.6μ region (we assumed that the observations were made at sufficiently large elongation angles that contributions to the scattered light from a forward scattering lobe would be negligible). The emitted radiation was determined by integrating their results for $5\mu \leq \lambda \leq 60\mu$. (Where no 1.25μ and 1.65μ data were presented, the ratio $\frac{I(1.65\mu)}{I(2.2\mu)}$ was assumed to be constant.)

Summary

Upper limits to the diffuse background radiation in the intermediate infrared ($5\mu \leq \lambda \leq 23\mu$), as measured from a sounding rocket, are presented. An excess signal was observed from the direction of the ecliptic plane, and is attributed to thermal emission from the interplanetary medium. It is possible that the minimum signals observed in the flight also can be accounted for by the same emission mechanism, since the minimum signal was observed near (i.e. within 20°) the ecliptic plane.

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TABLE I

Detector	$\lambda(\mu)$	NEI(1),(2)	Min Detected Intensity(1)	Min Signal(1) -scattered earth light	Ecliptic Flux(1)	
					Upper limit (pass 1)	(pass 2
Ge:Cu	5-6	1.3×10^{-13}	3×10^{-11}	2×10^{-11}	$<6.5\times10^{-11}$	3×10^{-1}
Ge:Cu	12-14	8×10^{-14}	3×10^{-11}	2×10^{-11}	$<7.0\times10^{-11}$	6.0×10^{-1}
Ge:Cu	16-23	2.3×10^{-14}	1.8×10^{-11}	1.2×10^{-11}	$< 4\times10^{-11}$	$2.5\times10^{-}$
Ge:Ga	70-130	6×10^{-14}	1.4×10^{-12}	1.0×10^{-12}	$<1.4\times10^{-12}$	$< 9\times10^{-}$

(1) Intensity watts/cm^2-str-μ

(2) Noise Equivalent Intensity

References

Allen, C.W., Astrophysical Quantities, Second edition, University of London, The Athlone Press (1964).

Harwit, M., Liege Symposium, 26, 506 (1964).

Harwit, M., Houck, J.R. and Fuhrmann, K., Appl. Opt. 8, 473 (1969).

Kleinmann, D.E., Lee, T., Low, F.J. and O'Dell, C.R., Astrophys. J., 165, 636 (1971).

Pipher, J.L., to be published (1971).

Pipher, J.L., and Houck, J.R., Appl. Opt. 10, 567 (1971).

Pipher, J.L., Houck, J.R., Jones, B.W. and Harwit, M.O., to be published, Nature (1971).

Quist, T.M., Proc. IEEE, 56, 1212 (1968).

Figure Captions

Figure 1 Scan path of telescope (in ecliptic coordinates, ϵ is elongation angle, α is elevation angle) from nose cone and telescope cover eject until +350 seconds.

Figure 2 Intensity as a function of zenith angle for 16μ-23μ detector during the second crossing of the ecliptic plane. BB' is the contribution from scattered earthshine, to which the telescope responds in the following way. At small off-axis angles θ, there is a strong forward peak of half power width, $1\frac{1}{2}^{\circ}$ defined by the telescope's field stop. At larger angles, in the range shown, a function of the form $A \exp-(\theta/\theta_o)$, with $A \sim 10^{-3}$ and $\theta_o \sim 8^{\circ}$ represents the telescope response. The main contributions to this response come from radiation scattered by the telescope's black walls and subsequently scattered a second time by imperfections and dust on the primary mirror. We would expect the imperfections to scatter less at long wavelengths so that the near infrared off-axis response should be less than that measured for visible radiation in the laboratory. At longer wavelengths, around 100μ, our paint becomes less "black" (Pipher and Houck (1971)) and an increase in off-axis response is to be expected. These expectations are consistent with the inflight measurements.

Figure 3 Intensity as a function of ecliptic elevation angle for 12μ-14μ and 16μ-23μ detectors (with scattered earthshine subtracted, as explained in the caption for Fig. 2).

Figure 4 Peak intensity during second pass across ecliptic plane, as a function of wavelength (scattered earthshine subtracted).

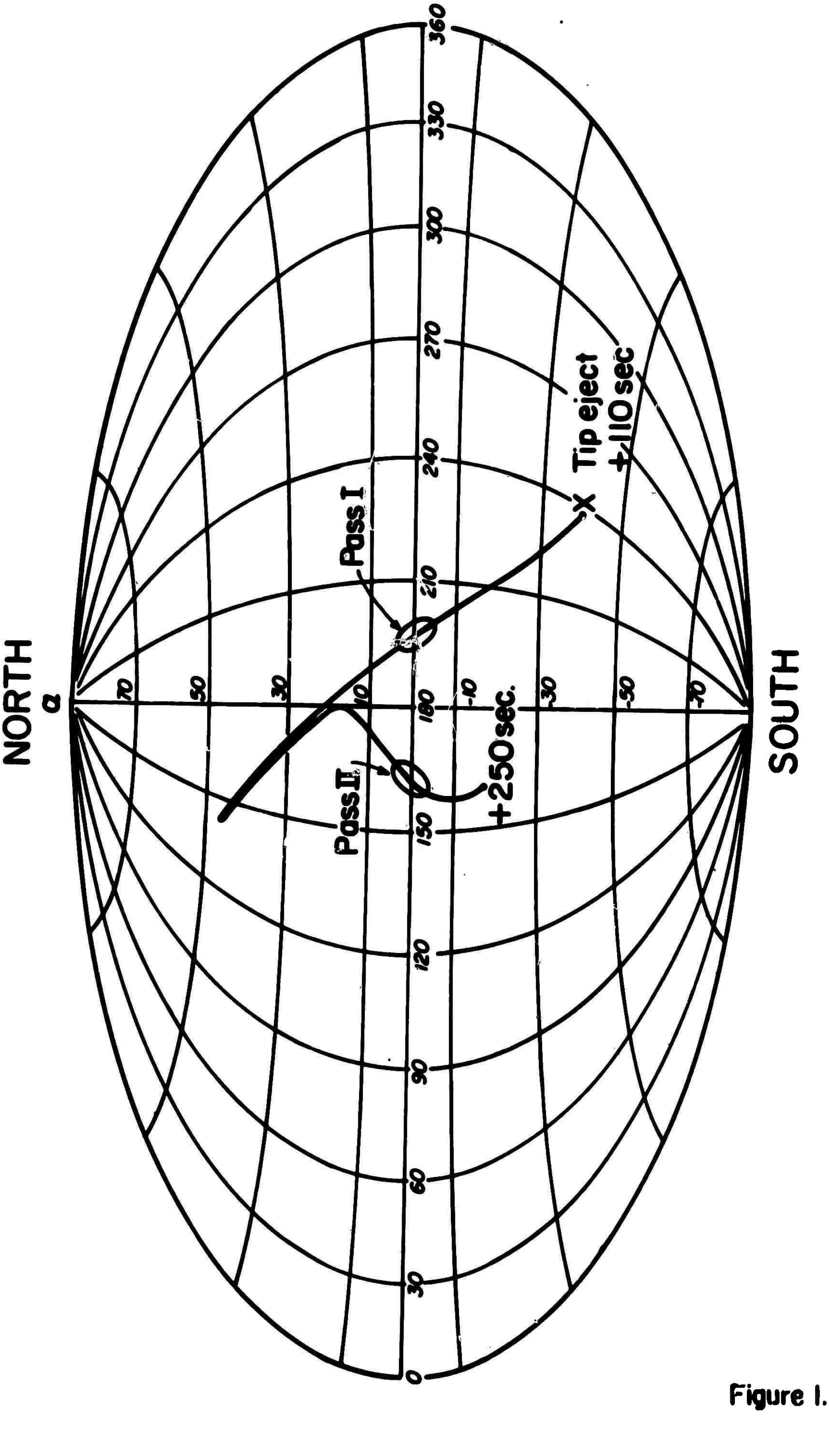
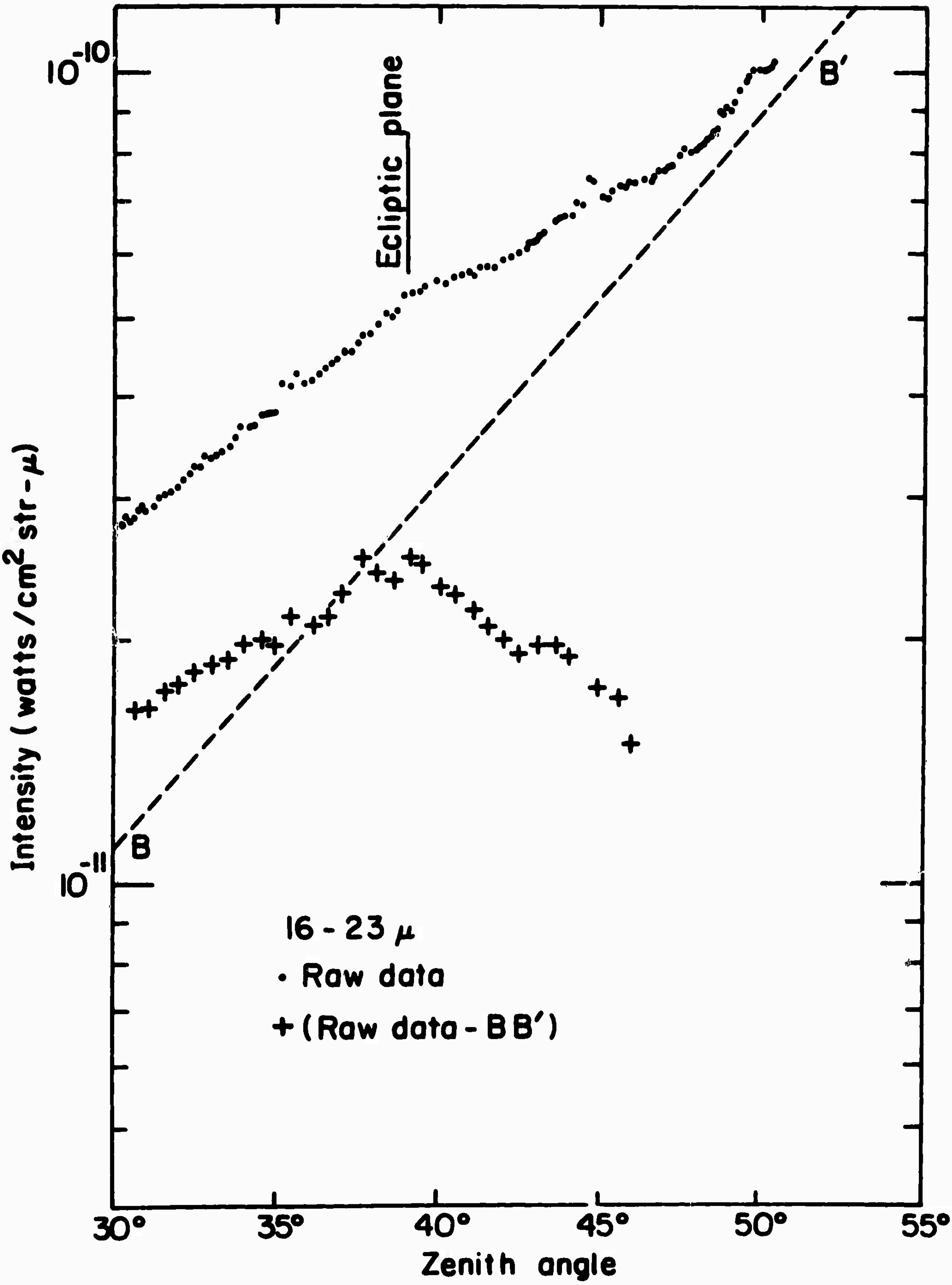
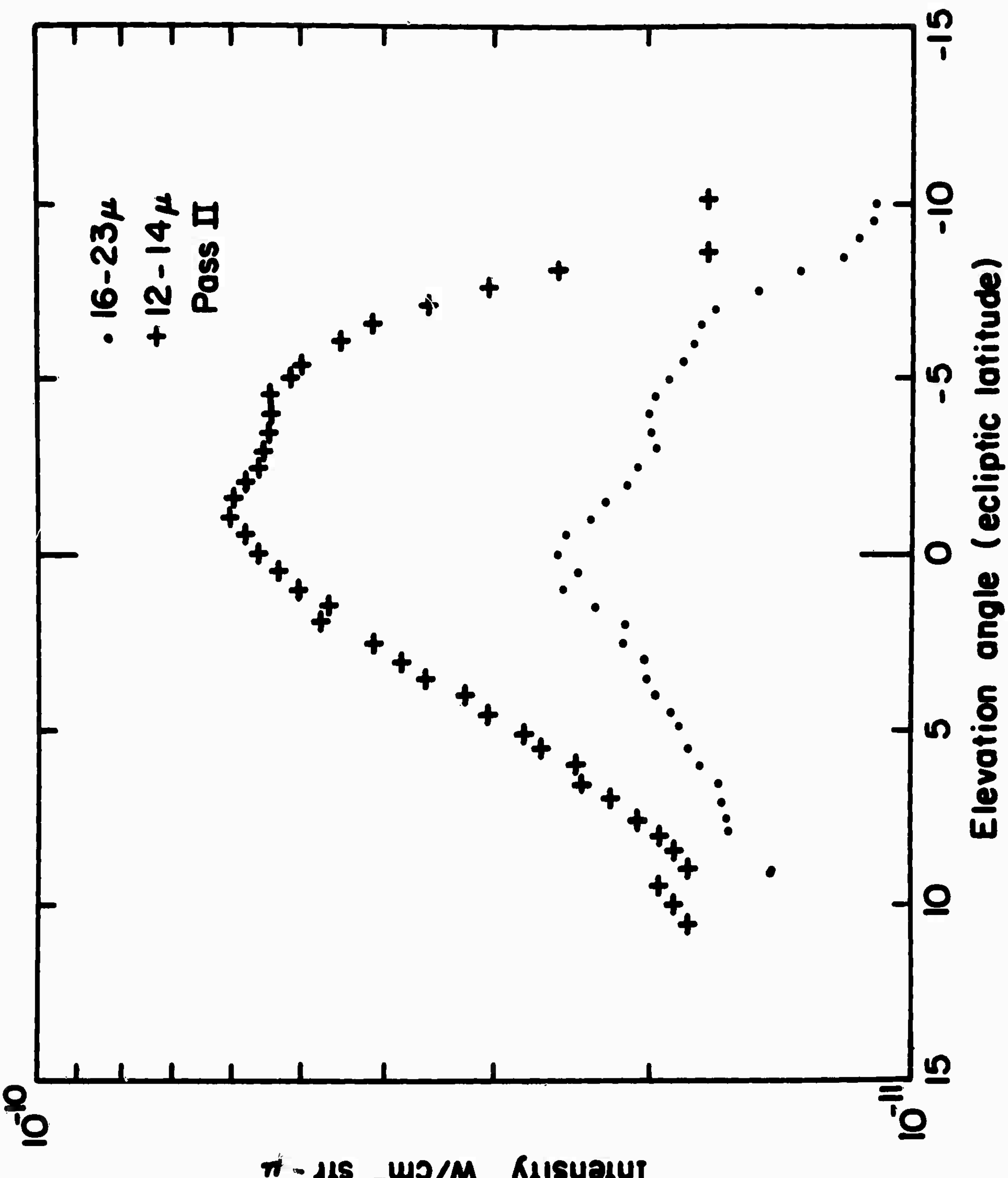

NORTH
α
SOUTH
Pass I
Pass II
Tip eject
+110 sec
+250 sec.
0
30
60
90
120
150
180
210
240
270
300
330
360
70
50
30
10
-10
-30
-50
-70

Figure 1.



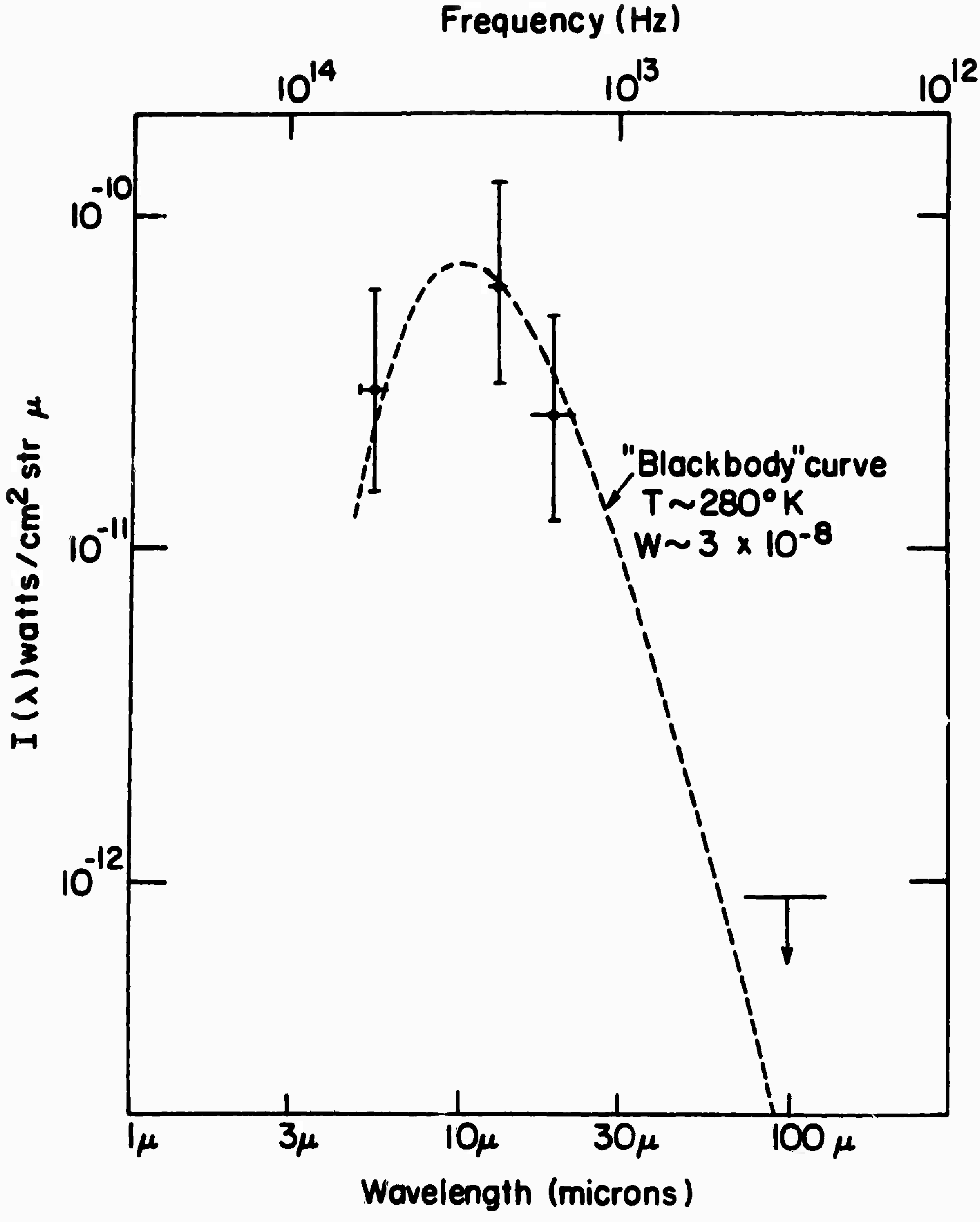
Ecliptic plane
10^{-10}
10^{-11}
B
B′
Intensity (watts /cm^2 str - μ)
16 - 23 μ
• Raw data
+ (Raw data - BB′)
30°
35°
40°
45°
50°
55°
Zenith angle

Figure 2.



· 16-23μ
+ 12-14μ
Pass II
Elevation angle (ecliptic latitude)
Intensity W/cm² str - μ
10^{-10}
10^{-11}
15
10
5
0
-5
-10
-15

Figure 3.



Frequency (Hz)
10^{14}
10^{13}
10^{12}
10^{-10}
10^{-11}
10^{-12}
I (λ) watts/cm² str μ
"Blackbody" curve
T ~ 280° K
W ~ 3 x 10^{-8}
1μ
3μ
10μ
30μ
100 μ
Wavelength (microns)

Figure 4.

B. Submillimeter Observations of the Night Sky Emission Above 120 Kilometers

Judith L. Pipher, J.R. Houck*, Barrie W. Jones and Martin Harwit

New diffuse background measurements of the night sky obtained with three submillimeter detectors are reported. These observations were made on December 2, 1970. A liquid-helium cooled telescope was carried by an Aerobee 170 to an altitude of 190 km. Six detectors covering bandwidths in the 5μ-1.5mm range were flown: the results from the near infrared detectors will be reported separately.[1]

Previous measurements in the 0.4-1.3mm range[2,3] yielded the unexpectedly strong submillimeter flux of $5^{+5}_{-2.5}\times10^{-9}$ watts/cm^2-sr. Subsequent detector recalibration[4] lowered this value to $2.5^{+2.5}_{-1.2}\times10^{-9}$ watts/cm^2-sr. However, even with the recalibration, this flux corresponded to an energy density of 6.5 ev/cm^3, as compared with a total energy density of the 2.7°K field of 0.25 ev/cm^3 of which 0.17 ev/cm^3 would fall in the 0.4-1.5mm bandwidth. Experiments by other groups have allowed these results to be viewed in a new perspective: Muehlner and Weiss[5] using increased spectral resolution in the same wavelength range found that their measurements were consistent with a 2.7°K background and a strong emission feature at 11-12 cm^{-1} superimposed. Bortolet, et al.[6,7] from observations of interstellar absorption lines, obtained new upper limits on the intensity of background radiation at wavelengths of 1.32mm, 0.559mm and 0.359mm that are consistent with a cosmic 2.7°K background. However, they can only be understood in conjunction with the infrared background measurement if the intense flux is concentrated into sharp line(s) ($\frac{\Delta\lambda}{\lambda}\leq 1/3$) which do not overlap with the molecular resonances of

*Alfred P. Sloan Research Fellow

CN, CH and CH^+. The diffuse Galactic gamma ray component ($E_\gamma \geq 100$ Mev) has been measured by several authors[8,9,10,11]: the measurements as they now stand are not inconsistent with a large infrared background, provided that it is Galactic.[12] An upper limit to the infrared background has been obtained by Hudson et al.[13] who have measured the diffuse X-ray component from the galactic plane in the energy range 7.7-115 keV. They find an upper limit to the infrared background of 1.7×10^{-9} watts/cm^2-sr if it is universal, assuming that the local intensity of ~ 3 Gev electrons is uniform throughout the galaxy.

The purpose of our flight was to make measurements with a more sensitive version of the 0.4-1.5mm InSb detector in a modified payload, in order to verify earlier results and obtain more detailed information on the isotropy of the radiation field. In addition, a second submillimeter detector, (GaAs) whose bandwidth (0.2-0.45mm) included the wavelength of the CH^+ line at 0.359mm, was flown for the first time. A third submillimeter detector, Ge:Ga, sensitive at 0.07-0.13mm, is useful not only because of the galactic information it can yield,[14] but also because it allows one to infer the magnitude of telescope heating or scattered light at the longer wavelengths. This detector measurement yields an upper limit to the submillimeter background at 100μ.

Instrumentation

This set of rocket infrared observations made use of a telescope system similar in many ways to that reported previously.[3,15] However, a number of modifications were made. Although the same telescope (18 cm mirror, prime focus, f/0.9) was used on this flight, the fields

of view of the various detectors were no longer common, nor as large as before. Each detector had a separate aperture defining its own field of view of 2 square degrees.

The three submillimeter detectors flown were a Gallium-doped germanium (Ge:Ga) detector, a Gallium Arsenide (GaAs) detector and a Rollin detector (n-type InSb). Both the Ge:Ga and InSb type detectors had been flown previously, but this is the first time the submillimeter GaAs detector has been successfully used for astronomical observations. (Laboratory experiments describing the development of this detector are given in reference[16].) The spectral responses of the detectors and their accompanying filters were measured with a lamellar grating attachment for a Perkin Elmer 301 Far Infrared Spectrophotometer built by Jones et al.[17] The InSb detector was strongly filtered by an interference filter and a sheet of black polyethylene against its intrinsic response, and had a long wavelength cutoff defined by two wire mesh filters. Strong atomic oxygen emission at 63μ and 147μ[18] from the upper atmosphere was rejected by the use of suitable Yoshinaga filters[19] in front of the Ge:Ga and GaAs detectors. Black polyethylene, bonded to the Yoshinaga filters, served to eliminate the intrinsic responses of these detectors.

The interior housing of the telescope was painted with a specially prepared paint, black in the infrared, and suitable for cryogenic use.[20] Rigid cylindrical inner and outer baffles served to eliminate stray radiation: the interior surfaces of both baffles were painted black. The inner baffle, thermally coupled to the liquid helium bath, remained at $4.2^{\circ}K$ throughout the observations, while the outer baffle stayed at $35^{\circ}K$. Temperature sensors on the telescope

wall and the detector block confirmed that a temperature of 4.2°K persisted throughout the flight.

System Calibration of the Detectors

The system noise equivalent power (NEP) of each detector was determined in the laboratory by means of a blackbody calibration. As has been described elsewhere,[21] a 77°K blackened cavity was placed over the aperture of the telescope. The amount of flux incident on the detectors was controlled by an adjustable shutter mechanism. The NEP's measured in this way are given in Table 1.

TABLE I

Detector	Spectral Range(μ)	NEP (watts-sec$^{1/2}$)	Minimum Observed Signals (watts/cm^2-sr)
Ge:Ga	70-130	4.5×10^{-13}	$8.5 \times 10^{-11} \pm 0.1$
GaAs	200-450	9×10^{-12}	$8 \times 10^{-11}\ {}^{+6}_{-4}$
InSb	400-1500	2×10^{-12}	$1.3 \times 10^{-9}\ {}^{+0.1}_{-0.15}$

The Flight

The rocket, with the liquid helium cooled telescope, was launched at 01:32 MST on December 2, 1970. A roll-stabilized Attitude Control System (ACS) was used to point the telescope. The path scanned in the sky up to 227 seconds into the flight is shown in Figure 1. At this time, an ACS failure occurred. The position in the sky both before and after the ACS failure was monitored by means of an aspect camera.

From the time of nose cone eject at 120 km, until peak altitude at 190 km, the payload performed normally and the data reported here

was from this time segment. The ACS failure occurred just after peak altitude, causing the rocket to roll and cone for the rest of the flight.

The Data

The minimum signals (and the relative uncertainties) observed by the submillimeter detectors are listed in Table 1. We assign, somewhat arbitrarily, an absolute uncertainty of a factor of 1.5. Throughout this paper, the tabulated values have been used, even for upper limits. It should be noted that the absolute calibration error could change all of the intensity levels quoted by as much as a factor of 1.5.

The level quoted for the GaAs detector is considered to be an upper limit, as the signal to noise ratio is of the order of one ($S/N \sim 1$). The estimate given for this detector is a 'Huberized' estimate;[22] this technique allows a reasonable assessment of noisy data. The effective integration time was chosen to be 5 seconds. (For the region of the sky used to evaluate the upper limit, namely the off-galactic scan, this integration in time corresponds to an average over five degrees of sky.)

The Ge:Ga minimum signal corresponds to a relatively open area of sky, and occurs at a zenith angle of 23°. At this zenith angle, there is only a small contribution by stray radiation from the earth, and the signal is well above the noise.

The minimum level quoted for the Rollin detector was observed both along the galactic scan ($b^{II} \approx 0^{\circ}$, $150^{\circ} \leq l^{II} \leq 210^{\circ}$) and off the galactic plane down to a latitude of $b^{II} = -27^{\circ}$. At galactic latitudes further south than -27°, the zenith angles were larger than

35°, the angle at which the InSb detector began responding primarily to scattered earthshine. The numbers quoted are also 'Huberized' averages. The errors quoted are for a 5 second average, and an average over this time scale essentially assumes the signal is uniform over five degrees. Estimates over a shorter time interval (1 second) had correspondingly larger error bars.

Discussion of the Data

1) InSb detector (0.4-1.5 mm)

The background signal observed by the InSb detector falls within the error of the previous recalibrated measurements, and should be considered another confirmation of the strong infrared background. Figure 2, a plot of the averaged data as a function of zenith angle illustrates a number of interesting features about this radiation. This figure also illustrates the signal level observed just before nose cone eject. This level is non-zero for the following reason. The top cover is cooled by contact with the inner baffle. After the last fill with liquid helium before the flight, the inner baffle normally warms up slightly, because of the heat load due to the cover. Until tip eject, radiation from the slightly warm baffle reflects from the top lid into the field of view of the detectors. At tip eject, the top lid and its heat load are removed, and the temperature sensors show that the inner baffle quickly cools to 4.2°K. There is good quantitative correlation between the baffle warmup and the observed signal increase before tip eject.

The minimum signal, for both 'on' and 'off' galaxy data is $1.3^{+0.1}_{-0.15} \times 10^{-9}$ watts/cm^2-sr for zenith angles less than 35°. The increasing flux at larger zenith angles is indicative of the detection of scattered earth radiation. Unfortunately, the baffling function of the telescope at these wavelengths is not sufficiently well known to uniquely determine the convolution of the baffling functions with the expected radiation from the earth. Hence an unambiguous interpretation of the observed intensity between zenith angles of 37° and 52° is not possible. However one can say that the contribution from scattered earth radiation for zenith angles less than 35° is small on the basis of the baffling function measurements.

The 'off' galaxy data cover a range of galactic latitudes from -5° to -27° at a galactic longitude of $\sim 163^\circ$, for zenith angles less than 35°. Bortolet et al.[6] have pointed out that line radiation, either from the atmosphere or the galaxy could account for the submillimeter background without producing a conflict with their measurements. Wagoner[23] discussed the implications of such line radiation from our galaxy: he assumed that the line shapes are Gaussian, and that, in order to explain the observed isotropy of the infrared background, the optical depth is larger than unity. Wagoner shows under these assumptions that the intensity I is given by

$$I \simeq \sum_r 4 \lambda_r^{-3} k T_e V (2 \ln \tau_r)^{1/2}$$

Here T_e ($\geq h \nu_r/k$) is the excitation temperature, V is the broadening parameter, τ_r is the optical depth at the line center ν_r, and the sum is over all resonances within the bandwidth. Since the optical

depth at $l^{II} = 163^{o}$ is related to the galactic latitude b^{II} by

$$\tau_r(b^{II}) \simeq \tau_r(b^{II} = 90^{o}) \csc(b^{II})$$

on the assumption that the emitting material is distributed uniformly in a disk, we can estimate the optical depth by considering the observed degree of isotropy of our submillimeter flux as a function of b^{II}. We find for a single line that

$$\tau_r(b^{II} = -90^{o}) \geq 12 \text{ (using error bars corresponding to a 5 sec average)}$$

using data from $-5^{o} \geq b^{II} \geq -27^{o}$.

Hence the observed isotropy (± 10% for our 5 second integrations) puts a fairly stringent lower limit on the optical depth of galactic line radiation, if it is the source of the submillimeter flux. The requirements are not impossible to satisfy within the Galaxy, so that strong galactic line emission is still consistent with these latest observations.

It is interesting to note, that in these 'off' galaxy data, no variance in the signal was noted as this detector crossed the ecliptic plane. The ± 10% isotropy implies an upper limit to the flux from zodiacal particles of $\sim 10^{-10}$ watts/cm^{2}-sr at 0.4-1.5mm.

In order to assess the likelihood of contamination from line (or band) radiation from the upper atmosphere, we can study the zenith angle dependence of the flux in Figure 2 and also study the intensity at a given zenith angle as a function of altitude. Observations at the same zenith angle, but at altitudes of 160 and 190 km, yield identical results to within the error. The atmospheric scale

height at these altitudes is ~ 25 km; one concludes from these identical results that the emitting material, if atmospheric, must primarily lie above 190 km. Dalgarno[24] has discussed the rotation spectrum of NO, N_2O and CO, all of which emit in the bandwidth of this detector. However, recent calculations by Shimazaki and Laird,[25] extrapolated to 190 km, indicate less than 10^2/cc of N_2O and 10^3/cc of NO. The CO concentration is less than that of NO and N_2O. These densities preclude night sky emission of the order of 1.3×10^{-9} watts/cm^2-sr from above 190 km unless a stimulated emission mechanism is invoked. It should also be noted that a sec θ dependence (appropriate for either a Doppler broadened or Lorentzian line shape in the weak-line limit) is excluded by the observations shown in Figure 2. A $(\sec \theta)^{1/2}$ or slower dependence (typical of the strong-line limit) could barely satisfy the observations, in light of the ambiguity of the exact scattered earthshine function. However, we do not know of any emitting substance with sufficient abundances at these altitudes to explain the observed radiation.

A local origin (inside the telescope) of the signal seems ruled out on several counts. First, the temperature of the telescope interior during the data collection phase of the flight remained at 4.2°K. Second, stray multiply reflected radiation would register more strongly on both the GaAs detector, and the Ge:Ga detector. Many details of this flight differed from that of previous flights, including a more efficient rejection filter, yet all flights yield similar results, within the error, under different conditions and surveying different paths in the sky.

The new 0.4-1.5mm measurement is plotted in Figure 3 for comparison with a thermal 2.7°K background and the other submillimeter measurements.

2) <u>GaAs detector (200-450μ)</u>

The GaAs measurement of the submillimeter background corresponds to an upper limit of ~ 14 x 10^{-11} watts/cm^2-sr. A 2.7°K thermal cosmic background as inferred by the absolute radio measurements, is not in conflict with this measurement or with the molecular measurements. Both this direct upper limit and the indirect molecular measurements suggest a spectral turnover for $\lambda < 1$ mm, as expected if the cosmic background is, indeed, thermal. The measurement is important for another reason; if the InSb measurement was in fact due to scattering or warmup of the telescope interior, this detector would have recorded correspondingly larger signals. Because this signal is an upper limit, little information about the isotropy of the radiation can be inferred.

3) <u>Ge:Ga detector (70-130μ)</u>

The minimum signal detected, 8.5 x 10^{-11} watts/cm^2-sr, was observed at a zenith angle of 23° and at an altitude of 186 km. Because we are only interested here in establishing an upper limit to the infrared background at this wavelength, we will not discuss discrete sources of the observed flux. We only mention that the signal is at least four times larger than the expected stray radiation from the earth (from an extrapolation of the curve measured at large zenith angles) and is unlikely to be contaminated by 63μ radiation from atmospheric atomic oxygen, because the response at

63μ was $\leq 0.5\%$ of that at 100μ. The most likely source of the bulk of the signal is radiation from interstellar grains; also since the ecliptic is only 17° away from the position in the sky of the minimum signal, radiation from interplanetary grains cannot be ruled out, and will be discussed by Soifer, et al.[1]

However, despite these other likely sources for the 100μ signal, the minimum observed signal stands as an upper limit to the cosmic background and is plotted on Figure 3 for comparison with the other observations. This detector is extremely sensitive to stray earth radiation. (A $280^{\circ}K$ blackbody emits $\sim 10^{3}$ more energy in the Ge:Ga bandwidth than in the InSb bandwidth.) If the InSb minimum signal at small zenith angles were caused by scattered earth-shine, then the Ge:Ga detector should have been saturated at $\sim 10^{-6}$ watts/cm^2-sr at these zenith angles. Thus we are assured that the strong 0.4-1.5 mm flux is not from such a cause.

Conclusion

This latest set of direct submillimeter observations above 120 km give a confirmation of the background flux in the 0.4-1.5 mm band that is in excess of a $2.7^{\circ}K$ blackbody, and upper limits to the background at 0.07-0.13 mm and 0.2-0.45 mm (see Figure 3). We feel that the measurement at 0.4-1.5 mm indicates that the flux is not of local origin, from stray radiation, or atmospheric in nature. Lower limits to the optical depth of galactic line emission, if it is the source of this flux, have been set by the isotropy of the observed flux. Our upper limit at 0.2-0.45 mm is not in conflict with a thermal $2.7^{\circ}K$ background or the molecular measurements. A

further understanding of the submillimeter background should be gained from subsequent flights. In particular, further measurements (with increased resolution) of the isotropy of the 0.4-1.5 mm flux should indicate whether a galactic origin of the flux is most likely, or whether an extragalactic origin is indicated.

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References

1. Soifer, B.T., Houck, J.R. and Harwit, M., in preparation (1971).

2. Shivanandan, K., Houck, J.R. and Harwit, M., Phys. Rev. Lett. 21, 1460 (1968).

3. Houck, J.R. and Harwit, M., Astrophys. J. Lett. 157, L45 (1969).

4. Harwit, M., Houck, J.R. and Wagoner, R.V., Nature 228, 451 (1970).

5. Muehlner, D. and Weiss, R., Phys. Rev. Lett. 24, 742 (1970).

6. Bortolet, V.I., Thaddeus, P. and Clauser, J.F., Phys. Rev. Lett. 22, 307 (1969).

7. Bortolet, V.I., Shulman, S. and Thaddeus, P., private communication (1971).

8. Clark, G.W., Garmire, G.P. and Kraushaar, W.L., Astrophys. J. Lett. 153, L203 (1968).

9. Garmire, G.P., Bull. Am. Phys. Soc. 15, 564 (1970).

10. Kniffen, D.A. and Fichtel, C.E., Astrophys. J. Lett. 161, L157 (1970).

11. Frye, G.M., Albats, P.A., Zych, A.D., Staib, J.A., Hopper, V.D., Rawlinson, W.R., and Thomas, J.A., preprint (1971).

12. Garmire, G.P., private communication.

13. Hudson, H.S., Peterson, L.E. and Schwartz, D.A., Nature 230, 177 (1971).

14. Stein, W., Astrophys. Journ. 144, 318 (1966).

15. Harwit, M., Houck, J.R. and Fuhrmann, K., Appl. Opt. 8, 473 (1969).

16. Stillman, G.E., Wolfe, C.M. and Dimmock, J.O., P.I.B. Intl. Symp. on Submillimeter Waves (1970).

17. Jones, B.W., and Houck, J.R., Appl. Opt. 9, 2582 (1970).

18. Bates, D.R., Proc. Phys. Soc., London B64, 805 (1951).

19. Sakai, K., Nakagawa, Y. and Yoshinaga, H., Japan J. Appl. Phys. 7, 792 (1968).

20. Pipher, J.L. and Houck, J.R., Appl. Opt. 10, 567 (1971).

21. Houck, J.R. and Harwit, M., Science 164, 1271 (1969).

22. Huber, P.J., Annals of Math. Stat. 35, 73 (1964).

23. Wagoner, R.V., Nature 224, 481 (1969).

24. Dalgarno, A., Phil. Trans. Roy. Soc. London A264, 153 (1969).

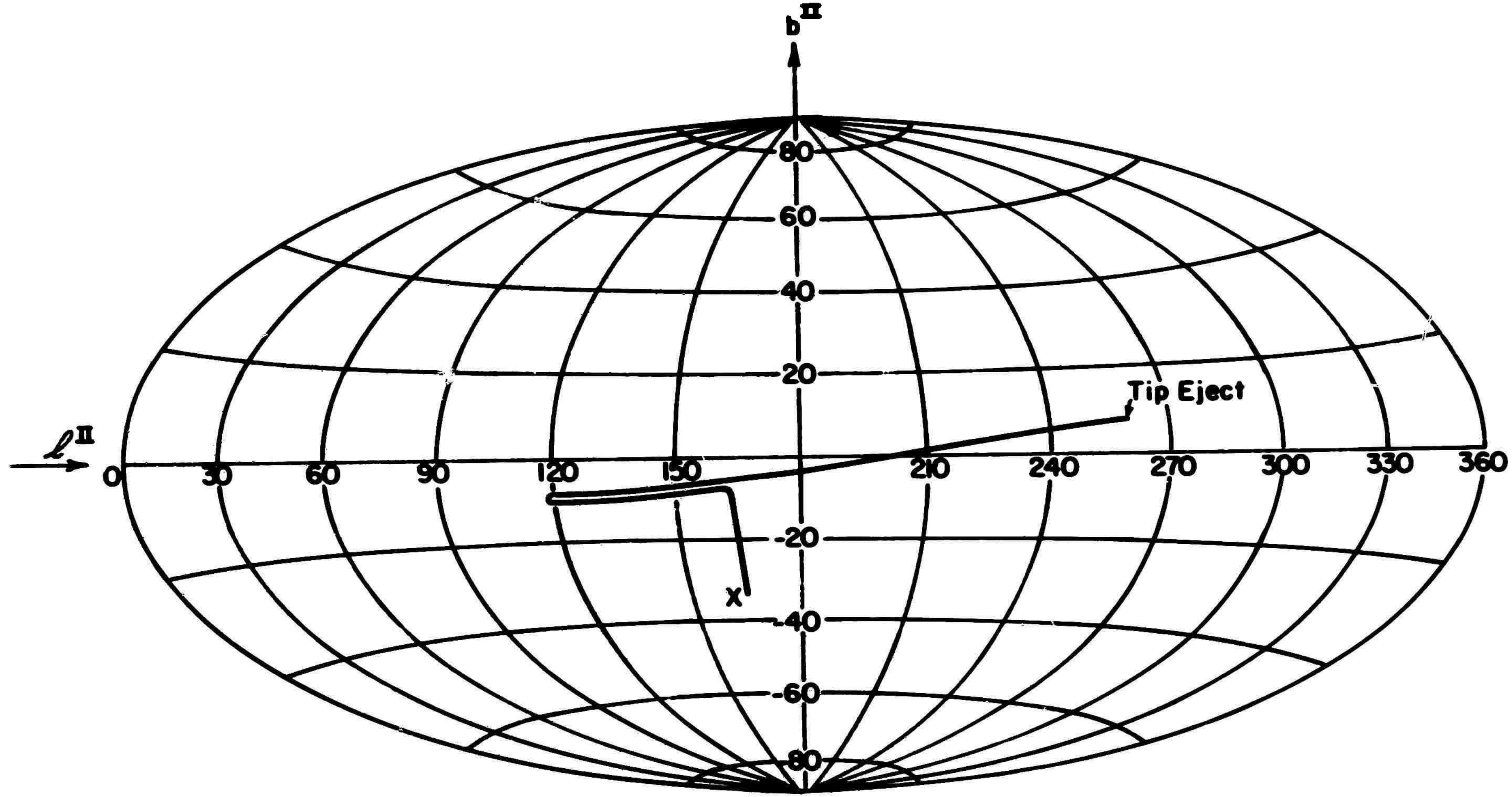
25. Shimazaki, T. and Laird, A.R., Jour. Geoph. Res. 75, 3221 (1970).

Figure Captions

Figure 1 Scan position in galactic coordinates from tip eject (nose cone and cover ejected) until the ACS failure (marked by an X).

Figure 2 Observed signal strength for the InSb detector (0.4-1.5mm) as a function of zenith angle. The 'on' galaxy points refer to data from the scan along the galactic plane, while the 'off' galaxy points refer to data from the scan perpendicular to the galactic plane. The error bar shown is typical for data in the range $10^\circ \geq \theta \geq 37^\circ$. The intensity level indicated just before tip eject was non-zero because of the reason explained in the text.

Figure 3 A comparison of the flux from a 2.7°K blackbody with the submillimeter measurements of this experiment and the revised upper limits to the background determined from observations of interstellar absorption lines by Bortolet, Shulman and Thaddeus.



b^{II}
ℓ^{II}
80
60
40
20
-20
-40
-60
-80
0
30
60
90
120
150
210
240
270
300
330
360
Tip Eject
X

Figure 1.

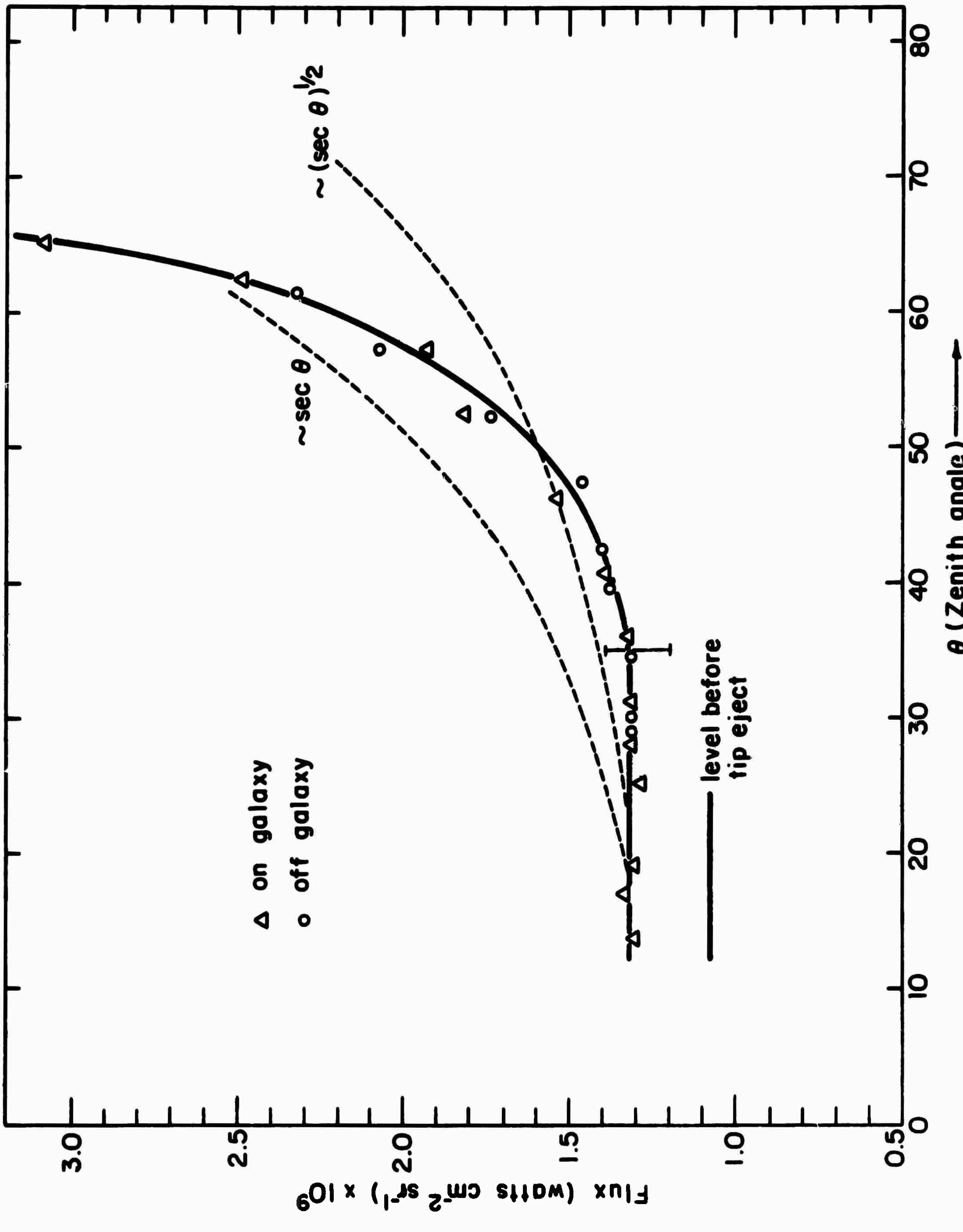

Flux (watts cm^{-2} sr^{-1}) x 10^9
3.0
2.5
2.0
1.5
1.0
0.5
0
10
20
30
40
50
60
70
80
θ (Zenith angle)
∆ on galaxy
o off galaxy
~sec θ
~(sec θ)$^{1/2}$
level before tip eject

Figure 2.

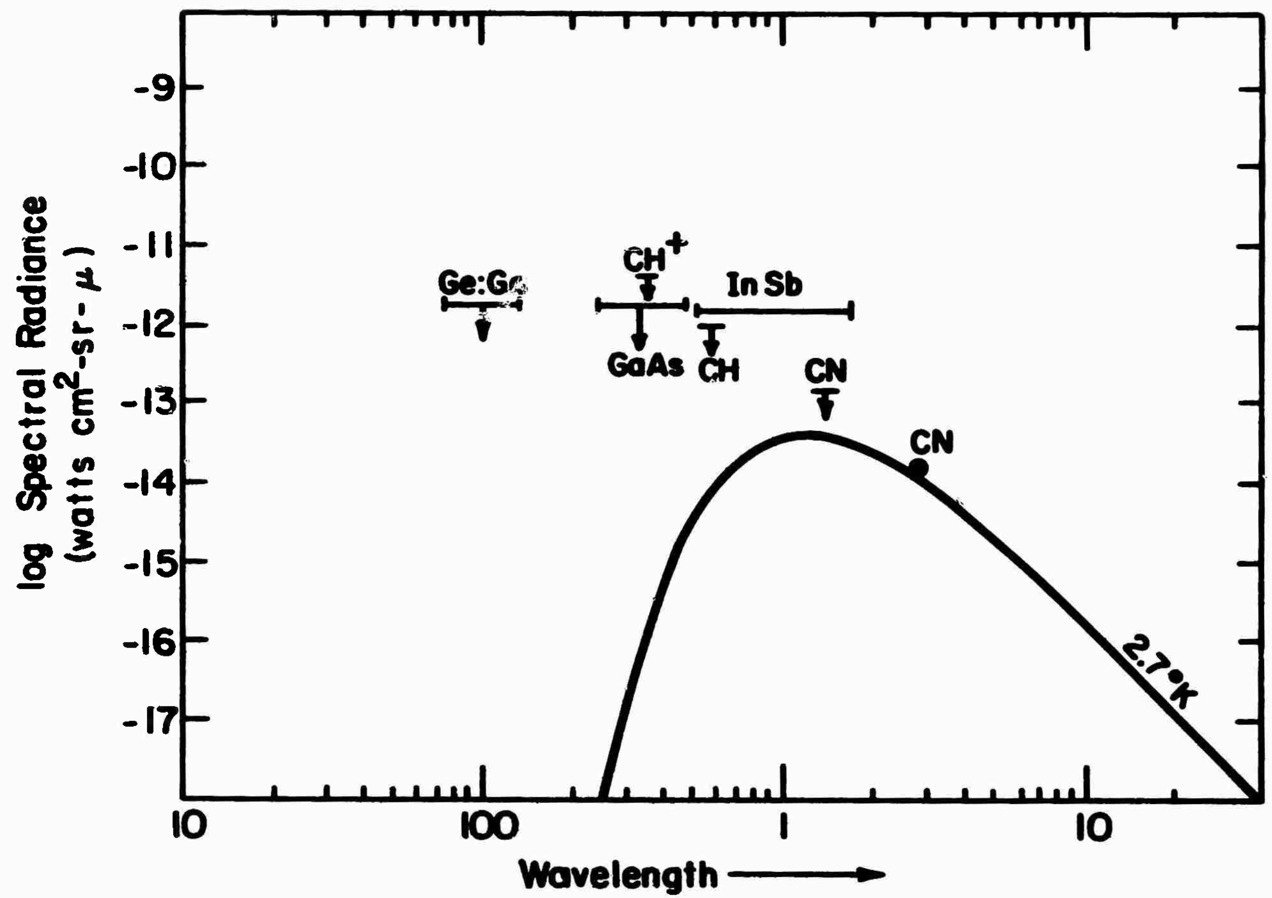

log Spectral Radiance
(watts cm²-sr-μ)
-9
-10
-11
-12
-13
-14
-15
-16
-17
10
100
1
10
Wavelength
Ge:Ga
CH+
GaAs
In Sb
CH
CN
CN
2.7°K

Figure 3.